Quantifying Differences in Water Quality Metrics in the South Fork and East Branch Tributaries of the Sugar Creek Watershed, Ohio

A Thesis Presented in Partial Fulfillment of the Requirements for The Honors Study Program in the School of Environment and Natural Resources in The Ohio State University

By Roxanne Anderson

Abstract

One of the most influential factors of water quality is nutrient pollution, notably agricultural inputs of nitrogen (N) and phosphorus (P) compounds, which have been a growing problem for the last few decades, contributing to algal blooms and eutrophication in freshwater systems. The Sugar Creek Watershed, located in the predominantly agricultural region of northeastern Ohio, is identified by the Ohio EPA as one of the most polluted watersheds in the state due to nutrient loading. Within the Sugar Creek watershed, two adjacent agricultural subwatersheds, the South Fork and East Branch tributaries, are characterized by different agricultural land use practices, specifically Amish versus non-Amish conventional farmers. These watersheds have been the focus of an ongoing water quality monitoring program, with the intent to provide benchmarks on the water quality status in these systems to inform targeted community based watershed stewardship programs. However, these data have not been summarized, which is a necessary step to identify which areas of a watershed have high or low water quality. The objectives of this study are to broadly compare nutrient concentrations (ammonia, nitrate, total nitrogen, phosphate, and total phosphorous) in these two subwatersheds and evaluate downstream nutrient concentration patterns specifically in the South Fork watershed for the period between 2006 and 2012. The data for each of the sites in the South Fork watershed (mainstem and tributaries) were evaluated both annually and seasonally from 2006 to 2012. Nutrient concentrations in the South Fork tributary are generally higher than the East Branch tributary, and both subwatersheds have overall total phosphorous and total nitrogen concentrations that exceed proposed statewide concentrations in Ohio. Visual inspection of annual averages of each nutrient concentration at each sample site in the South Fork indicates variability between years and seasons. Seasonally, nutrient

concentrations are generally lowest in the spring and highest either in summer (NH_3, TN, and TP) or autumn (PO_4^{3-}), which is interpreted to reflect the timing of fertilizer application. Within the South Fork tributary, statistical differences exist between the mainstem sample sites and suggest significant downstream trends of increasing nutrient concentrations at least for phosphorous nutrients. More detailed research is needed to more rigorously evaluate the effect of Best Management Practices (BMPs), which were implemented in tributaries within the South Fork watershed in 2006, as well as other environmental variables on water quality such as topography and soil characteristics and land use/land cover, including the presence of riparian buffers.

Introduction

Water quality issues have been a growing problem for decades (Carpenter et al. 1998). It is widely recognized that one of the most influential factors of water quality is nutrient pollution (Carpenter et al. 1998; Matson 1997; Smith 2003). A nutrient is a chemical compound that an organism needs to sustain life and grow. Nutrient pollution is the contamination of water by an excess of input from nutrients, the most common culprits being nitrogen N and P (Boesch et al. 2001; Carpenter et al. 1998; Schindler 1971). The loading of nutrients from human activities in streams and rivers causes the pollution, which in turn affects lakes, wetlands, and coastal regions (Stevenson et al. 2012; Carpenter et al. 1998). High levels of nutrients and sediments in water can pose significant health risks and negatively affect human recreation and ecological biodiversity (Stevenson et al. 2012; Peterjohn and Correll 1984; Jones et al. 2001; Somura et al. 2012).

Nutrient pollution is the primary cause of eutrophication. Eutrophication is the process where excessive inputs of both P and N stimulate algae growth and the decomposition of organic matter, which causes a depletion of dissolved oxygen that can approach anaerobic or anoxic conditions (Somura et al. 2012; Boesch et al. 2001). Eutrophication can occur under very small concentrations of P (Hart et al. 2004). Freshwater eutrophication is a growing problem, with the common occurrence of eutrophication being algal blooms (Carpenter et al. 1998; Somura et al. 2012). Phosphorous loading into waterways from runoff and leaching is one of the leading causes of eutrophication and dangerous algal blooms in the U.S. (Hart et al. 2004; Stevenson et al. 2012; Mainstone et al. 2002).

Nutrient pollution is discharged from two different types of sources: point and nonpoint. Nutrient pollution that is discharged from point sources, such as industrial or sewage treatment plants, is continuous, with little variability over time, and is relatively simple to regulate and measure since it is commonly discharged from one source that is easily identifiable, such as a pipe (Carpenter et al. 1998; Somura et al. 2012). Nutrient pollution that is discharged from a nonpoint source is also sometimes continuous but is difficult to regulate and measure as the source is nondiscrete, extending over a large area such as from agricultural activity, and is often linked with seasonal or irregular events (Carpenter et al. 1998). Consequently, nonpoint discharge is a major source of water pollution in the U.S.

Since the 1950s, N inputs have tripled as the result of agricultural fertilizer applications (Herrman et al. 2008). The excess in nitrogen added to water systems is shown to degrade habitats and limit biodiversity and is also linked to eutrophication (Herrman et al. 2008). Nitrogen is easily transported in water and remains stable over a wide range of conditions (Jones et al. 2001). It moves from the land after application via ground and surface water (Herrman et al. 2008; Stevenson et al. 2012), and concentrations are linked with agricultural activities in winter and early spring, as well as runoff in summer and autumn (Osborne & Wiley 1988; Johnson et al.1997). One of the largest causes attributed to the increase in nutrient pollution in the past few decades is the change in land use from natural forested land cover to agricultural use with fertilizer application (Skaggs et al. 1994).

A land conversion from forest to agricultural production results in the introduction of high fertilizer concentrations to the soil and waterways. The change in land use causes change in the types of ground cover, such as row crops or pasture, depending upon the season, as well as alterations in the routes and rates of agricultural runoff (Skaggs et al. 1994). Collectively, these changes result in more rapid delivery of excess nutrients to streams and rivers. There is an effort in conducting research to reduce the amount of N and P inputs from agricultural runoff, but there are many factors that influence N and P behavior that cause high variability in the findings between different studies (Boesch et al. 2001; Johnson et al. 1997; Skaggs et al. 1994). Factors affecting variability include vegetation cover, crop size and rotation, underlying geology, which affects water chemistry, ground water transport, and residence time, drainage methods, and soil and fertilizer amounts and types (Boesch et al. 2001; Johnson et al. 1997; Skaggs et al. 1994).

Within the state of Ohio, there have been recent severe outbreaks of algal blooms that have increased the awareness on nutrient loading from nonpoint agricultural runoff. Trends in agricultural practices have correlated with increased P loading to the Lake Erie basin, resulting in record breaking nutrient loads that caused the largest harmful algal bloom in Lake Erie's history in 2011 (Michalak et al. 2013).

Sugar Creek Watershed Water Quality Research

The Sugar Creek watershed, located in the northeastern part of the state in a predominantly agricultural area, is identified by the Ohio EPA as one of the most polluted watersheds in Ohio due to nutrient loading (OEPA 2002; Fig. 1). Numerous studies conducted by The Ohio State University, some of which are still ongoing, have contributed to an increased understanding of nutrient loading and agricultural processes. In particular, a water quality monitoring program, largely composed of nutrient concentration sampling, was implemented in 2002 in various subwatersheds within Sugar Creek to better understand the spatial and temporal variability in water quality metrics and provide a benchmark for each subwatershed on which to assess future watershed improvement efforts (Moore et al. 2008). Partnerships were developed among landowners throughout the watershed to implement Best Management Practices (BMPs) in one region of the watershed, which are intended to offset nutrient loading in other regions of a watershed. This process is referred to as "nutrient trading", and the Sugar Creek watershed has served as a model for community-based watershed projects (Parker et al. 2007, 2009; Moore et al. 2008).

Other studies within the Sugar Creek watershed have focused on stream and riparian processes within the watershed. Herrman et al. (2009) evaluated the effect of riparian land use in headwater streams. They found that the ability for nutrients to travel through soil and ground water before draining into a stream was similar between agricultural and forested reaches. However, forested reaches had more potential to retain nutrients due to complex root systems and organisms in this land cover resulting in a longer travel time (Herrman et al. 2009). However, another study by some of the same authors that assessed nitrogen removal capacities from headwater streams reported little difference between agricultural and forested reaches (Herrman et al. 2008). Goebel et al. (2011) reported that the structure of riparian vegetation communities, notably, the presence of simplified canopy structures, reflects surrounding land use types in this watershed (Goebel et al. 2011).

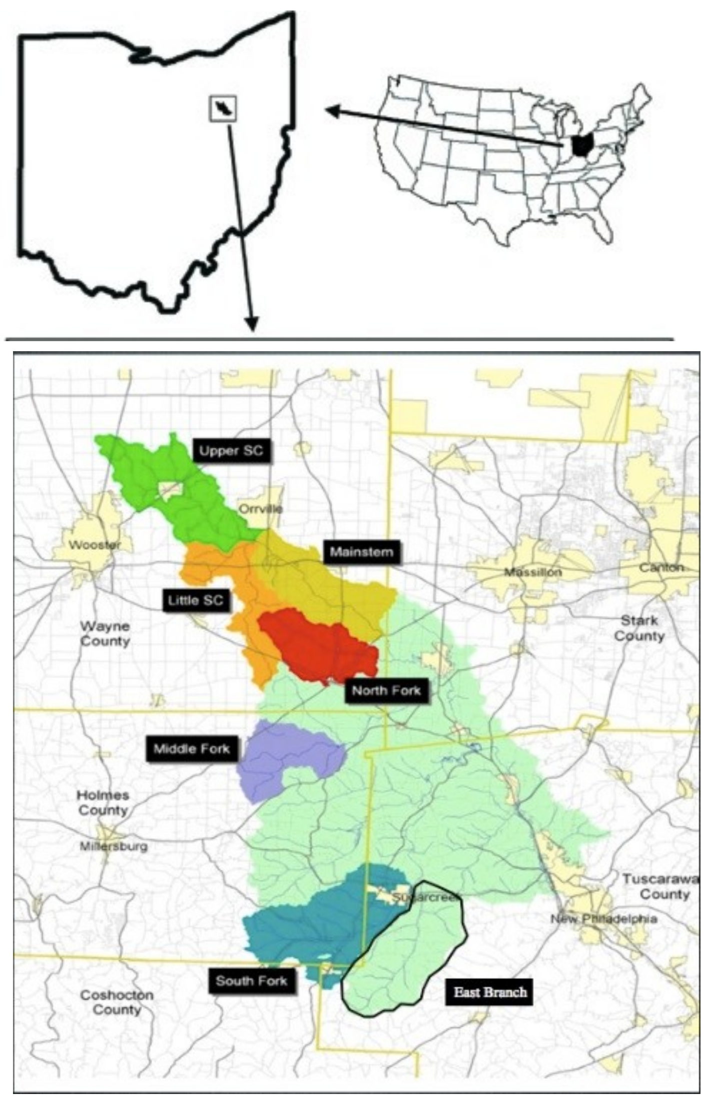

__Figure 1.__ The Sugar Creek watershed. The Sugar Creek mainstem flows from north to south. South Fork and East Branch subwatersheds are located in the southern portion of the watershed.

Finally, a study of the importance of riparian forests to aquatic food webs found that there was no significant difference in $\delta^{13}C$ signatures and $\delta^{15}N$ signatures in between forested and non-forested sites in an agricultural landscape. These results suggested that basal resources are not the only mechanism driving the structure of the aquatic food web (Goebel et al. 2010).

Research Objectives

Different land uses affect nutrient loading in adjacent waterways (Skaggs et al. 1994). Within the Sugar Creek watershed, two adjacent agricultural subwatersheds, the South Fork and East Branch tributaries, are characterized by different agricultural practices and land use practices. The South Fork subwatershed is settled by predominantly Amish farms that produce dairy and row crops of corn and vegetable cash crops (Parker et al. 2009). Ohio has the largest Amish population in the world, with the majority (>70%) located in the Sugar Creek watershed (Parker et al. 2009). The Amish do not use mechanized farming equipment and generally have smaller land plots; however, they do not necessarily employ less intensive farming practices. For example, Amish farmers will apply conventional fertilizer to crops in addition to the traditional manure application. The South Fork has been the focus of an intensive water quality monitoring program as well as implementation of BMPs in smaller tributaries that flow into the South Fork mainstem (Moore et al. 2008). The East Branch subwatershed is predominantly non-Amish and characterized by conventional row crop and dairy farming.

The research objectives are to (1) broadly compare the nutrient concentrations in these two subwatersheds and (2) evaluate downstream nutrient concentration patterns in the South Fork watershed. It is expected that the Amish South Fork tributary will show lower nutrient concentration than the non-Amish East Branch tributary, due to Amish farming techniques. While the scope of this project does not include a detailed analysis of different land use practices and their relationship to water quality metrics, a general summary and analysis of water quality patterns both between the two subwatersheds and within an individual subwatershed provides information on the water quality of these subwatersheds, including the effectiveness of current BMP measures, and can be used to guide future watershed projects. This analysis uses the nutrient concentration data collected by the Sugar Creek Research Team at OARDC from 2006 through 2012. Streamflow discharge data do not exist for these subwatersheds; therefore, analysis is limited to nutrient concentration. Precipitation data collected from the National Oceanic and Atmospheric Administration is used in an attempt to detect potential relationships between concentration and precipitation as a proxy for discharge.

Methods

Study Site

The Sugar Creek watershed covers 925 km^2 in northeast Ohio in Wayne, Stark, Holmes, and Tuscarawas counties (Fig. 1). The Sugar Creek mainstem is approximately 72 km long. The watershed is a tributary of the Tuscarawas River and flows into the Ohio River, which is a main source of nutrient loading in the Gulf of Mexico (OEPA 2002). More than 70% of the basin's land is dedicated to agricultural uses, including dairy, beef, and poultry confined feeding operations, row crops, and forage production (OEPA 2002). The South Fork tributary and the East Branch are two adjacent subwatersheds compared in this study (Fig. 1) and are located in the southern unglaciated quadrant of Ohio, which is characterized by a rolling topography. The watersheds' close proximity to each other is expected to minimize variability due to similar landscape and unglaciated soil composition. The South Fork tributary that is predominately Amish has a 65 km^2 drainage area and has about 14% forest cover, with the rest being a mix between pasture, crop, and livestock land uses. The East Branch tributary that is predominantly non-Amish has a 73 km^2 drainage area and has about 33% forest cover, with the rest being a similar mix to South Fork of pasture, crop, and livestock land uses.

<u>Objective 1. Comparison between Two Subwatersheds: South Fork and East Branch</u>

The first objective is to compare water quality metrics between the two sample subwatersheds of the South Fork and East Branch. Site 63 is used for the East Branch tributary, and site 59 is used for the South Fork tributary (Fig. 2). The decision to use site 59 instead of site 62 in South Fork is due to the importance of having similar drainage areas.

The parameters used from the nutrient concentration data collection project through OSU are as follows: NH_3 (ammonia), NO_3^- (nitrate), PO_4^{3-} (phosphate), TP (total phosphorus), TN (total nitrogen). Data were collected from 2006 to 2012 between March and November, with a twice per month frequency (~16-17 times each year). They were collected in 50 mL polypropylene centrifuge tubes that were preserved with 1 mL of 0.5 M sulfuric acid solution. The data that were collected out in the field using a water quality sonde (both YSI and HACH hydrolab brands). Once the samples were collected they were brought back to the lab and filtered through a 0.45 μm filter and then analyzed for NH_3, NO_3^-, PO_4^{3-}, TP, TN. The instrument used for this after 2010 was a LACHAT QuikChem 8500 Series 2 Flow Injection Analysis Automated Ion Analyzer, before 2010 a spectrophotometer was used to determine nutrient concentrations

The data are organized and graphically summarized using box plots. A Mann-Whitney U was conducted to determine any significant difference (significance of $p < 0.05$) between the medians of the parameters at the two sites overall and seasonally (spring (Mar-May), summer (Jun-Aug), autumn (Sep-Nov)). Annual Precipitation Summary Data from 2005 to 2012 were acquired from National Oceanic and Atmospheric Administration (NOAA) to identify potential relationships between precipitation and water quality concentrations. The precipitation summaries were averaged from the two closest data collection stations; Coshocton Agricultural Research Station, OH, which is approximately 31 km away, and Dennison Water Works, OH, which is approximately 23 km away. The data was tabulated and plotted to see if there was any relationship to nutrient concentrations and a regression was performed to determine if there was any correlation.

Objective 2. Analyzing Downstream Trends in Water Quality Metrics in the South Fork

The second objective is to compare longitudinal changes (in the downstream direction) in water quality in the South Fork tributary. This included a total of five mainstem sites (MB1-MB5) and two locations upstream of the mainstem (MB6a and MB6b) that serve as isolated branches that flow into the mainstem (Fig. 2). The data analyzed at these sites were the same as in Objective 1: NH_3, NO_3^-, PO_4^{3-}, TP, TN.
A chart graph of the data, both annually and seasonally, was initially done to identify any visual trends through time. Tests for significant differences between sample locations were

conducted using the non-parametric Kruskal-Wallis and a post-hoc, pair-wise comparison with a Bon Ferronni adjustment in significance level. The results were correlated to the differences of land use identified by a GIS analysis of the watershed. The data obtained from NOAA was tabulated and charted to identify potential relationships between nutrient concentrations and precipitation as a proxy for stream flow discharge.

Results

<u>Objective 1. Water Quality Differences between Two Subwatersheds: South Fork and East Branch</u>

Comparison between the two subwatersheds indicates that nutrient loads in the South Fork tributary are generally higher than the East Branch tributary, despite the

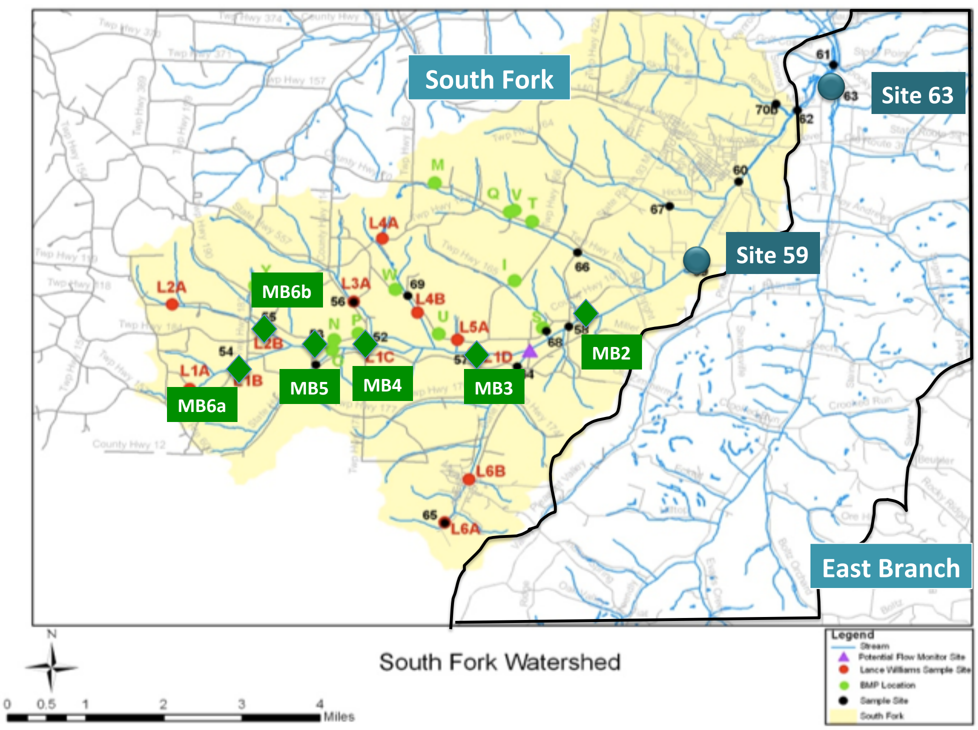

***Figure 2**. Data collecting sites in South Fork and East Branch with site 59 and site 63 denoted as collection sites used for Objective 1 (Adapted from Alex Joannon).*

implementation of BMPs in South Fork since 2007 (Table 1, Appendix A). Both subwatersheds have overall total phosphorous and nitrogen concentrations that exceed proposed statewide concentrations in Ohio (Fig. 3).

Phosphorous loads (TP and PO_4^{3-}) in the South Fork are significantly higher than in the East Branch overall and across all seasons (Table 1). NO_3^- is significantly higher in the South Fork overall and during autumn, but is not significantly different during spring and summer (Table 1). Total nitrogen (TN) and NH_3 are not significantly higher in the South Fork relative to the East Branch (Table 1, Appendix A). According to the EPA, there are no criteria currently set in Ohio for N and P standards for neither lakes/reservoirs nor lakes/streams; however, the *proposed* statewide criteria for N is 1 ppm and for P is 0.05 ppm (OEPA 1999). Wisconsin and New Jersey are two of the few states with set criteria for streams and rivers, both of which have a TP standard of 1 ppm. Wisconsin does not have a standard set for TN, but New Jersey has a standard of 2 ppm for NO_3^-. It is estimated that an EPA approved adoption of criteria for Ohio should be completed by May 31, 2014 ("State Development," n.d.).

Table 1. *Statistical summary and Mann-Whitney U test of sites 59 and 63. Values are in parts per million (ppm). P-values are calculated for the Mann-Whitney U test on medians. Values in* ***bold*** *are statistically significantly different.*

Variable	South Fork Mean	East Branch Mean	South Fork Median	East Branch Median	South Fork Standard Deviation	East Branch Standard Deviation	P-value
NH3							
Overall	*0.47*	*0.41*	*0.31*	*0.30*	*0.63*	*0.48*	*0.6082*
Spring	*0.31*	*0.21*	*0.29*	*0.22*	*0.23*	*0.14*	*0.2056*
Summer	*0.60*	*0.49*	*0.30*	*0.29*	*0.82*	*0.61*	*0.7189*
Autumn	*0.34*	*0.37*	*0.32*	*0.36*	*0.28*	*0.25*	*0.5768*
NO3							
Overall	**2.53**	**2.18**	**2.35**	**1.74**	**1.37**	**1.71**	**3.1E-03**
Spring	*3.22*	*2.48*	*2.96*	*2.60*	*1.50*	*1.35*	*0.0685*
Summer	*2.43*	*2.34*	*2.09*	*1.84*	*1.39*	*2.02*	*0.1289*
Autumn	**2.35**	**1.77**	**2.33**	**1.49**	**1.19**	**1.25**	**0.0307**
TN							
Overall	*3.85*	*3.39*	*3.28*	*2.77*	*2.77*	*2.66*	*0.1600*
Spring	*3.34*	*2.62*	*3.02*	*2.39*	*1.70*	*1.51*	*0.2180*
Summer	*3.93*	*3.54*	*3.27*	*2.73*	*2.94*	*2.95*	*0.3810*
Autumn	*4.01*	*3.59*	*3.56*	*3.29*	*2.99*	*2.63*	*0.4970*
PO4							
Overall	**0.75**	**0.21**	**0.43**	**0.11**	**0.84**	**0.33**	**2.2E-16**
Spring	**0.28**	**0.13**	**0.25**	**0.09**	**0.16**	**0.12**	**5.6E-04**
Summer	**0.62**	**0.19**	**0.43**	**0.09**	**0.54**	**0.25**	**1.4E-07**
Autumn	**1.13**	**0.30**	**0.68**	**0.14**	**1.19**	**0.47**	**6.4E-11**
TP							
Overall	**0.64**	**0.17**	**0.40**	**0.12**	**0.77**	**0.17**	**2.2E-16**
Spring	**0.20**	**0.09**	**0.19**	**0.07**	**0.08**	**0.06**	**6.2E-05**
Summer	**0.71**	**0.20**	**0.42**	**0.14**	**0.94**	**0.20**	**1.4E-09**
Autumn	**0.72**	**0.15**	**0.67**	**0.12**	**0.55**	**0.12**	**1.1E-11**

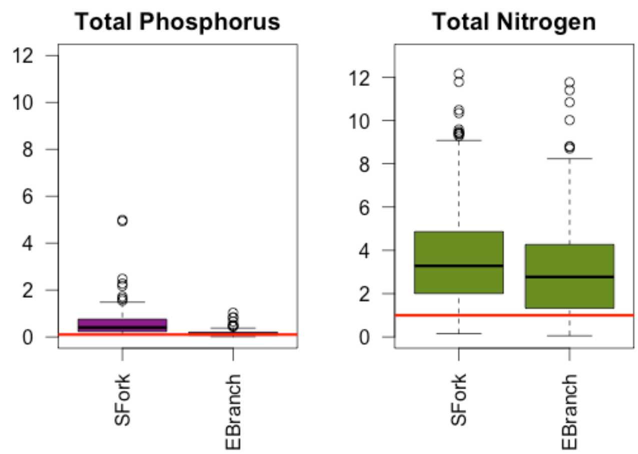

Figure 3. *TP and TN levels from 2006 to 2012 shown with a red line denoting the proposed statewide criteria for Ohio. The box represents the 25th and 75th percentile of the nutrient concentration values, the thicker horizontal lines within the box represent the median, and the whiskers represent the 5th and 95th percentiles.*

Annual Precipitation Summary Data provided by NOAA from 2006 to 2012 were averaged from the two closest data collection stations and charted. At this resolution of the data, there are no visual trends, clear relationships, or correlations between monthly precipitation averages and nutrient concentrations over the seven-year period (Fig. 4, Fig. 5, Appendix B). Therefore, we are not able to generalize nutrient concentration metrics to nutrient loads exported from the watershed.

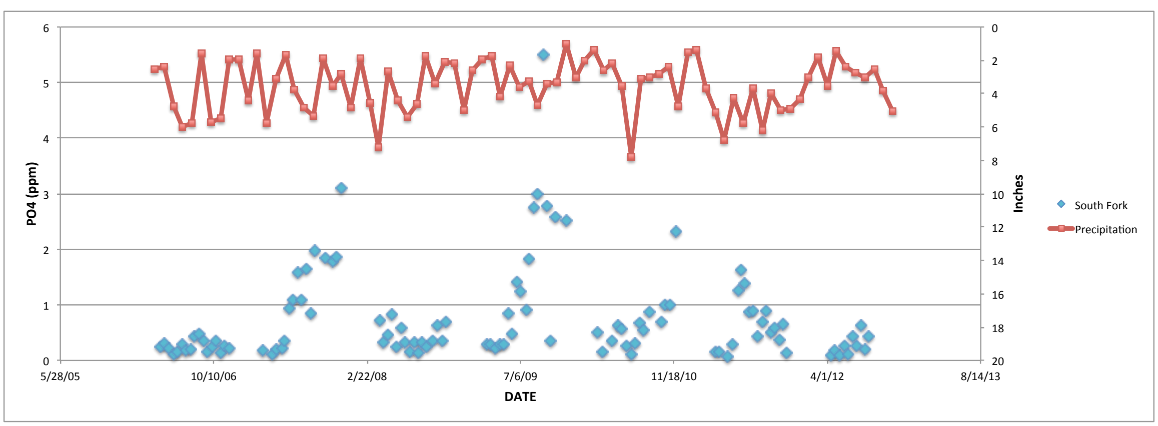

Figure 4. *Monthly precipitation compared to* PO_4^{3-} *concentrations at site 59, South Fork tributary. Nutrient concentrations and precipitation trends for other nutrients are reported in Appendix B.*

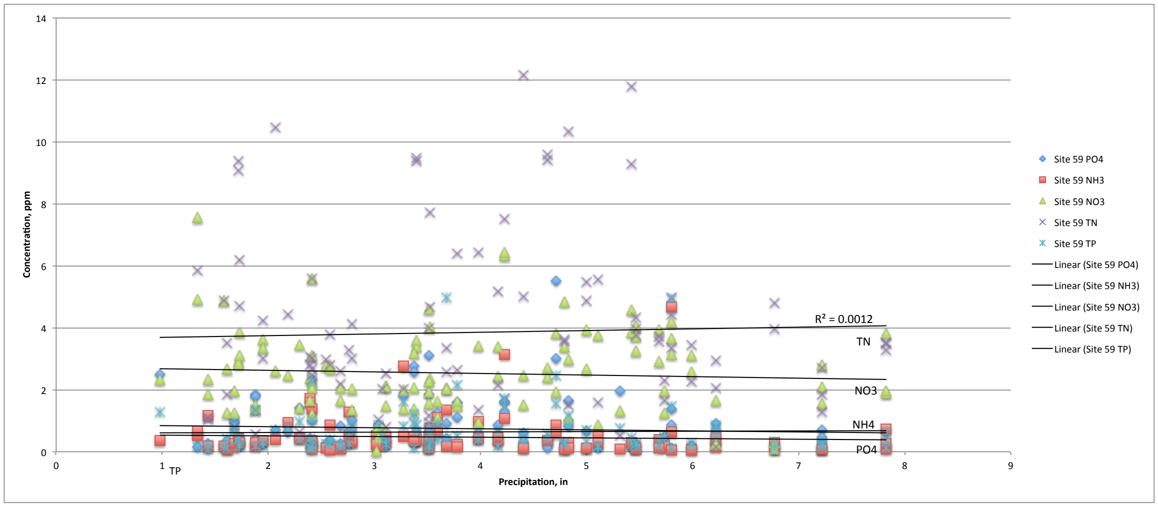

Figure 5*. Linear regression trend lines showing correlations between monthly precipitation and concentrations* of NH_3, NO_3^-, PO_4^{3-}, TP, TN *at site 59, South Fork tributary. Nutrient concentrations and precipitation correlations for site 63 is reported in Appendix B.*

Objective 2. Temporal and Downstream Trends in Water Quality Metrics in the South Fork

The data for each of the sites in the South Fork watershed (mainstem and tributaries) were evaluated both annually (Appendix C) and seasonally from 2006 to 2012 (Appendix D).

Trends through Time

Visual inspection of annual averages of each nutrient concentration at each sample site in the South Fork indicates variability between years. Mean overall NH_3 concentrations appear to be increasing through time in the mainstem from 2006 to 2010 but has been decreasing in the following two years (Fig. 6). Phosphate (PO_4^{3-}) generally appears to be decreasing in the middle and upstream mainstem sampling locations although there is substantial interannual variability in this nutrient metric (Fig. 7). No obvious trends are visually evident in other nutrient concentrations (e.g., decreasing nutrient concentrations through the years since BMP implementation; Appendix C).

Seasonally, NH_3, TN, and TP have the lowest concentrations in the spring followed by highest concentrations during summer (Appendix D). Summertime high nutrient concentrations may reflect fertilizer application activities and/or low stream flow conditions during the summer. PO_4^{3-} concentrations are highest in autumn and lowest in the spring (Fig. 8, Appendix D). Sites T1.1 and T1.2, which are both located on a tributary that enters the South Fork mainstem between MB1 and MB2, had generally higher nutrient concentrations, particularly during the summer, relative to all other sites within the watershed. However, both TN and NO_3^- had the highest concentrations in the spring (versus the summer) in this tributary relative to the main stem sample locations.

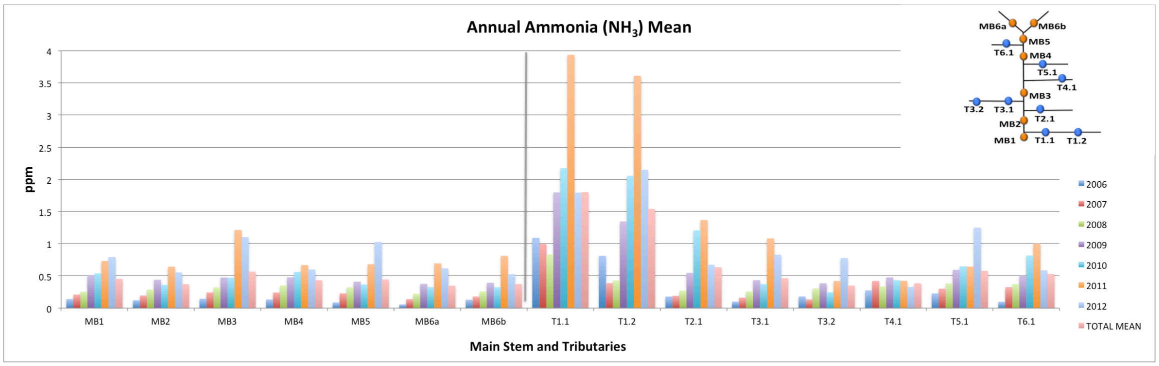

Figure 6. *Annual* NO_3^- *concentration at main branch (MB) left of the vertical line and tributary (T) sample sites right of the vertical line from 2006 to 2012. Schematic in upper right corner provides channel network configuration of the tributary and mainstem sample locations.*

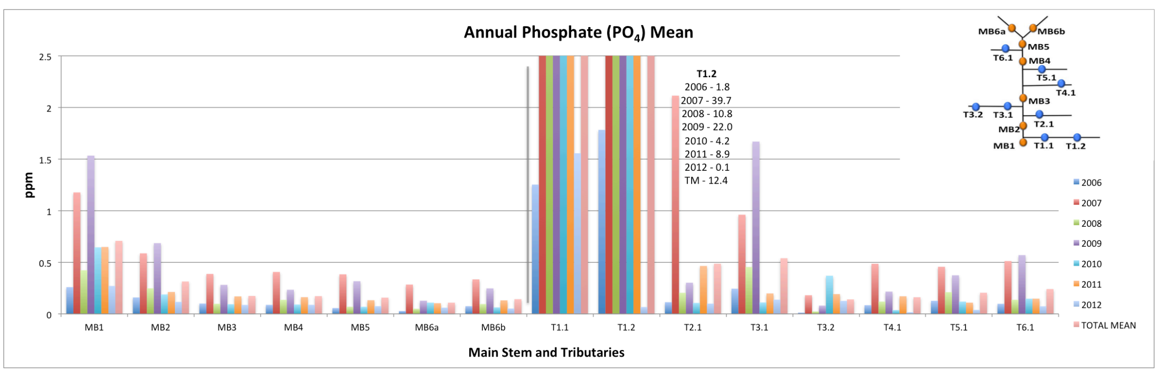

Figure 7. *Annual* PO_4^{3-} *concentration at main branch (MB) left of the vertical line and tributary (T) sample sites right of the vertical line from 2006 to 2012. Schematic in upper right corner provides channel network configuration of the tributary and mainstem sample locations.*

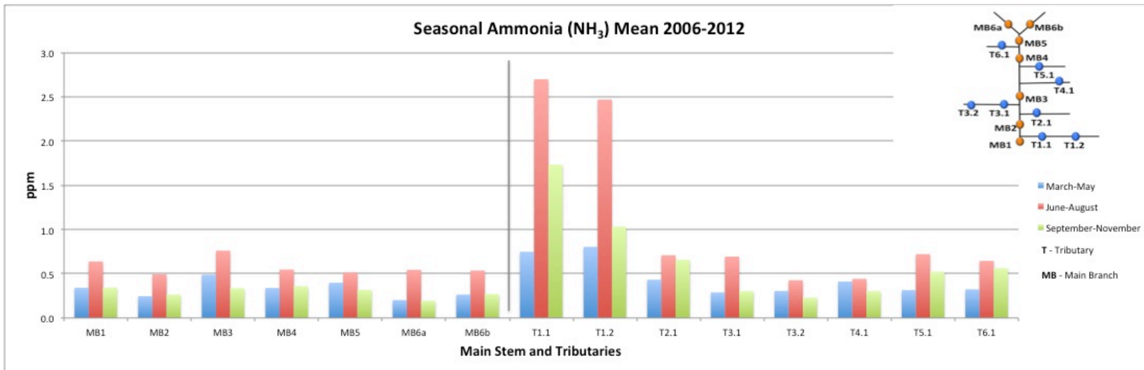

Figure 8. *Annual* NH_3 *concentrations at main branch (MB) left of the vertical line, and tributary (T) sample sites right of the vertical line from 2006 to 2012. Schematic in upper right corner provides channel network configuration of the tributary and mainstem sample locations.*

Downstream Trends

Statistical differences exist between the mainstem sample sites and suggest significant downstream trends of increasing nutrient concentrations at least for phosphorous nutrients in the South Fork. A Kruskal-Wallis test detected significant differences in nutrient concentrations among South Fork sample locations with the exception of TN (Table 2). Post-hoc pair-wise test with a Bon Ferronni adjustment, identify differences between specific sample locations. In terms of nitrogen compounds, differences only exist between the upstream sample location (MB6a), which is significantly lower in NH_3 relative to a middle mainstem location (MB3) and significantly lower in NO_3^- relative to its neighboring headwater sample location (MB6b) (Table 3).

Table 2. *Kruskal-Wallis tests on main branch sample sites in the South Fork tributary*

KRUSKAL-WALLIS	
Variable	P value
NH3	***0.0003***
NO3	***0.02***
TN	0.40
PO4	***2.20E-16***
TP	***2.20E-16***

Significant differences exist between sample locations in the mainstem for both PO_4^{3-} and TP and suggest increasing nutrient concentrations in the downstream direction (Table 4). In particular, PO_4^{3-} and TP concentrations are significantly higher in MB1, setting this site apart from all other sample sites (Table 5). MB2 is also significantly higher in PO_4^{3-} relative to all other sites, with the exception of MB1. The middle mainstem sample locations (MB3-MB5) are statistically similar. MB5 is similar to the upstream sample locations MB6a and MB6b. Although MB6a has lower PO_4^{3-} and TP concentrations these values are not statistically different from each other.

Table 3. *Average concentrations for nitrogen compounds indicating significant differences between main branch sample sites in the South Fork tributary*

Average concentrations for nitrogen compounds (2006-2012) for sample sites on South Fork Mainstem. Kruskal-Wallis and pair wise comparison to detect significant differences between sites.					
*Indicates differences in nutrient concentration between sites					
NH3		**NO3**		**TN**	
Site	Mean		Mean		Mean
MB1	0.46	MB1	2.58	MB1	3.92
MB2	0.35	MB2	2.49	MB2	3.77
MB3	**0.54***	MB3	2.53	MB3	4.00
MB4	0.42	MB4	2.46	MB4	3.74
MB5	0.42	MB5	2.58	MB5	3.98
MB6a	**0.33***	MB6a	**2.19***	MB6a	3.49
MB6b	0.37	MB6b	**2.89***	MB6b	4.13

Table 4. *Average concentrations of* PO_4^{3-} *at main branch sample sites in the South Fork tributary. Letter groups show significant differences between sites in the downstream direction from post-hoc pair-wise tests.*

Average concentrations for PO4 (2006-2012) for sample sites on South Fork Mainstem. Kruskal-Wallis and pair wise comparison to detect significant differences between sites. Letters identify sites that are not signifcantly different from each other.					
PO4					
	Mean	GROUPS			
MB1	0.75	A			
MB2	0.34		B		
MB3	0.18			C	
MB4	0.18			C	
MB5	0.16			C	D
MB6a	0.11				D
MB6b	0.15			C	D

Table 5. *Average concentrations of TP at main branch sample sites in the South Fork tributary. Groups show significant differences between sites in the downstream direction.*

Average concentrations for TP (2006-2012) for sample sites on South Fork Mainstem. Kruskal-Wallis and pair wise comparison to detect significant differences between sites. Letters identify sites that are not significantly different from each other.						
TP						
	Mean	GROUPS				
MB1	0.64	A				
MB2	0.25		B			
MB3	0.17		B	C		
MB4	0.16			C	D	
MB5	0.16			C	D	E
MB6a	0.12					E
MB6b	0.13			C	D	E

There appears to be no downstream trends in land cover in the South Fork tributary (Fig. 8). Specifically, the proportion of forest cover does not decrease in the downstream direction, nor does the proportion of agricultural land cover increase in the downstream direction. In the absence of downstream trends, comparisons between nutrient concentrations and land cover were not conducted.

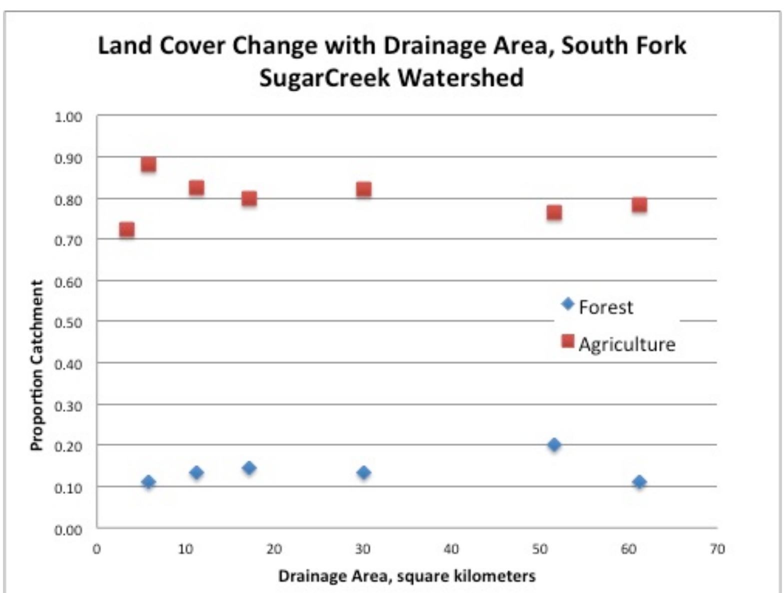

Figure 8*. Proportion of agricultural land cover and forest cover in the downstream direction (analysis by Zhouxin Xi, OSU).*

Discussion

The effect of the BMPs, located on the tributaries, cannot be evaluated because there are no recorded data for the watershed before implementation in 2006. However, despite their implementation, nutrient concentrations in the South Fork subwatershed continue to be elevated above statewide standards and are generally higher than the adjacent East Branch subwatershed. It is important to note that East Branch nutrient concentrations also exceed proposed statewide criteria. It is not clear if the general increase in nutrient concentrations in the downstream direction is a result of activity in the tributaries between the main branch sites or if it is a result of the concentrations accumulating downstream from upland areas adjacent to the mainstem. However, the distinctly higher P concentrations in both MB1 and MB2 are interpreted to be attributed to tributaries that discharge immediately above each of these sample sites. In particular, T1.1 and T1.2 consistently had significantly higher concentrations relative to the rest of the watershed.

Also, at the scale used, there does not appear to be any relationships with water quality and land cover. However, it is worth pointing out that the upper reach of the watershed, MB6a, which had the lowest nutrient concentrations, appears to be significantly different from the adjacent upper watershed. Focused investigation in this portion of the watershed may yield reasons for the higher water quality in this area, which can be a result of land use practices or other environmental variables such as topography or soil type.

While some Amish farming techniques may have contributed to the high nutrient concentrations, some of their farming techniques may contribute less to nutrient loading than that of the non-Amish. It is common that the Amish do not have much storage capacity for their manure, so they continuously apply it. Their manure is often stored in bare sheds and open areas that can be exposed to precipitation. Over-application and insufficient storage leads to excess in nutrient runoff, which could explain the high P concentrations that were found. Horses are used instead of tractors, and the "no till" method is used, both of which leads to less land compaction (Zook, 1994). Less phosphorous loading in adjacent stream channels could be a result of less soil compaction, which leads to less runoff, more water retention, and less sediment transport. Non-Amish farms tend to have larger plots and utilize more pesticides. Both the non-Amish and Amish farms in the Sugar Creek watershed were observed to have channelized drainage, which causes increases in nutrient loading from lack of filtration. While Amish tend to have different farming practices than non-Amish farmers, it is not conclusive that these practices would cause the nutrient increases shown.

While the monthly precipitation data does not show a clear relationship with nutrient concentration, this could be due to the broad data range. Data of specific precipitation events surrounding the dates when data were collected from the sample sites may show a clearer relationship.

Conclusion and Recommendations for Future Work

Nutrient pollution is a growing problem and is mostly caused by increased inputs of N and P. After analyzing the data collected from the sample sites in the Sugar Creek watershed, it was determined that the South Fork tributary has significantly higher concentrations of PO_4^{3-} and TP than the East Branch tributary. NO_3^- is significantly higher in the South Fork overall and during autumn, but it is not significantly different during spring and summer.

Annual precipitation summary data that were averaged from the two closest collection stations were found to have no clear relationship with nutrient concentrations on a month-to-month basis. A more in-depth study is recommended with daily precipitation values for a better representation of how precipitation events can affect nutrient concentrations when occurring simultaneously with water quality sampling.

Some visual trends in nutrient concentrations of annual averages through time may exist for mean overall NH_3 concentrations, which appear to be increasing through time in the mainstem, and phosphate (PO_4^{3-}), which appears to be decreasing in the middle and upstream mainstem sampling locations. However, further statistical analysis is necessary to confirm this finding. Seasonally, NH_3, TN, and TP have the lowest concentrations in the spring, followed by highest concentrations during summer. PO_4^{3-} concentrations are highest in the autumn and lowest in the spring.

Statistical differences exist between the mainstem sample sites and suggest significant downstream trends of increasing nutrient concentrations, at least for phosphorous nutrients in the South Fork. A Kruskal-Wallis test detected significant differences in nutrient concentrations among South Fork sample locations, with the exception of TN. Significant differences exist between sample locations in the mainstem for both PO_4^{3-} and TP and suggest increasing nutrient concentrations in the downstream direction.

After analyzing land use in the subwatersheds, the absence of downstream trends prevented comparisons between nutrient concentrations and land cover from being conducted. A land use analysis, and investigation into land practices may better link land use activities on water quality metrics.

Nonpoint source pollution of nutrient loading to freshwater systems remains a persistent challenge for agricultural regions of the U.S. This study serves as an example that ongoing water quality monitoring in watersheds such as in the South Fork watershed can begin to identify some benchmarks of water quality status of a watershed. However, more detailed research is needed to better evaluate more rigorously the effect of implemented BMPs as well as other environmental variables on water quality such as topography and soil characteristics and land use/land cover, including the presence of riparian buffers.

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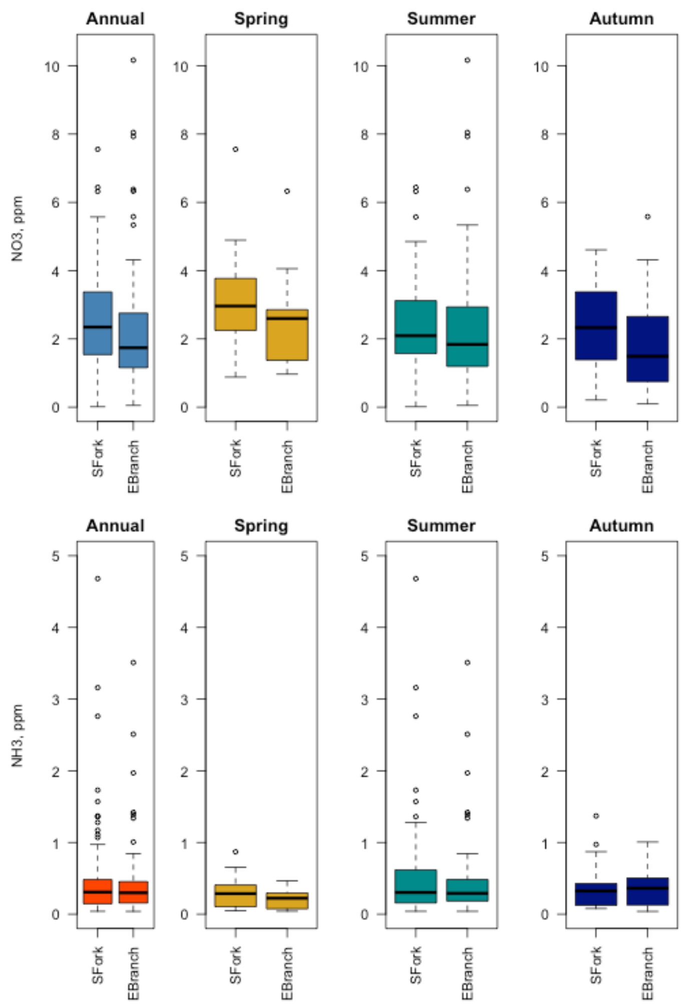
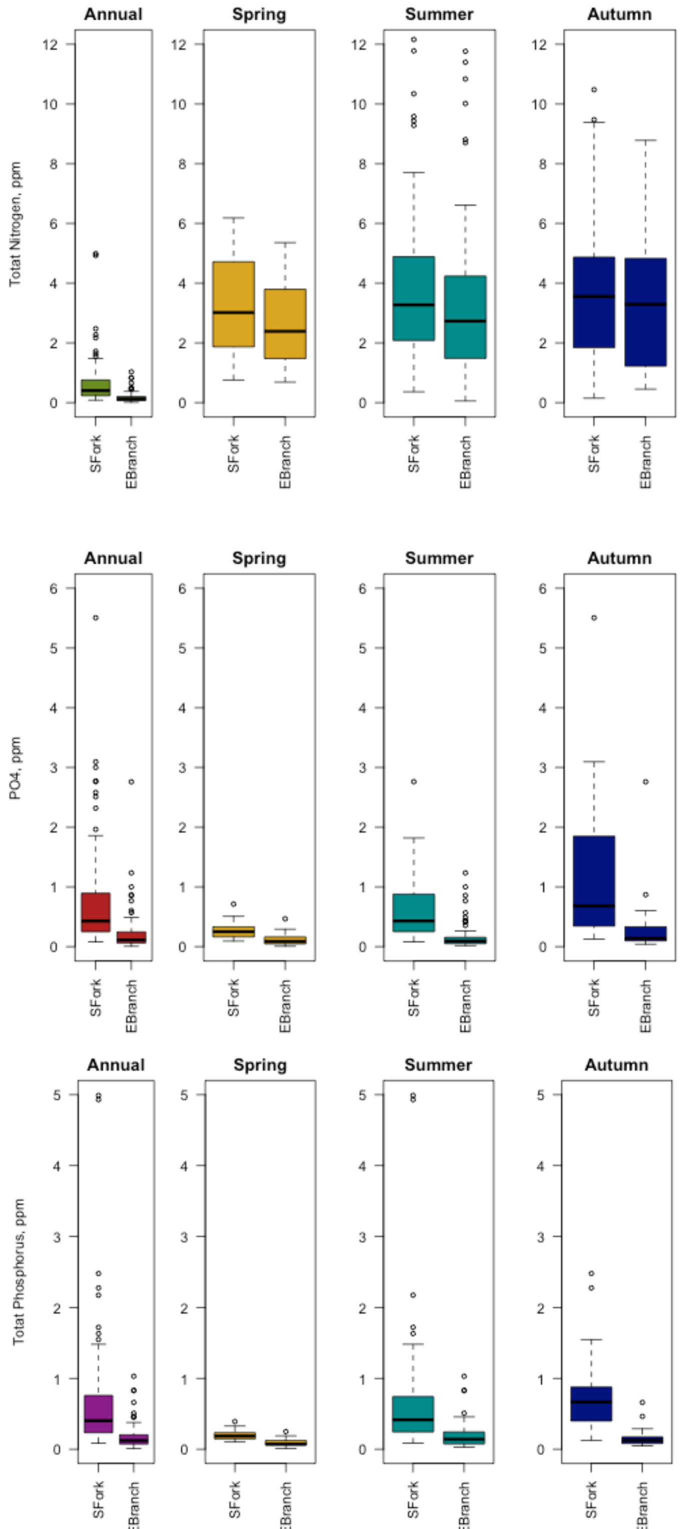
APPENDIX A

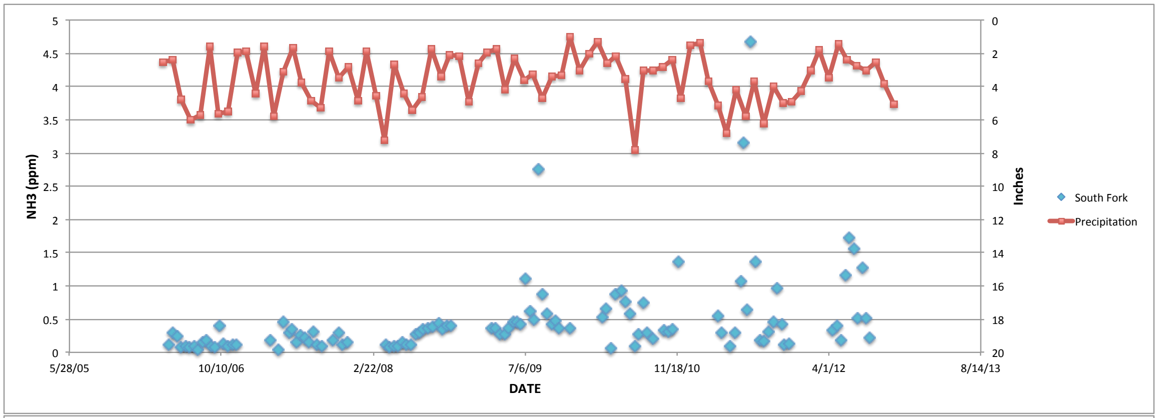
Overall and seasonal box plots of the nutrient concentrations between South Fork and East Branch subwatersheds. The box represents the 25th and 75th percentile of the nutrient concentration values, the thicker horizontal lines within the box represent the median, and the whiskers represent the 5th and 95th percentiles.

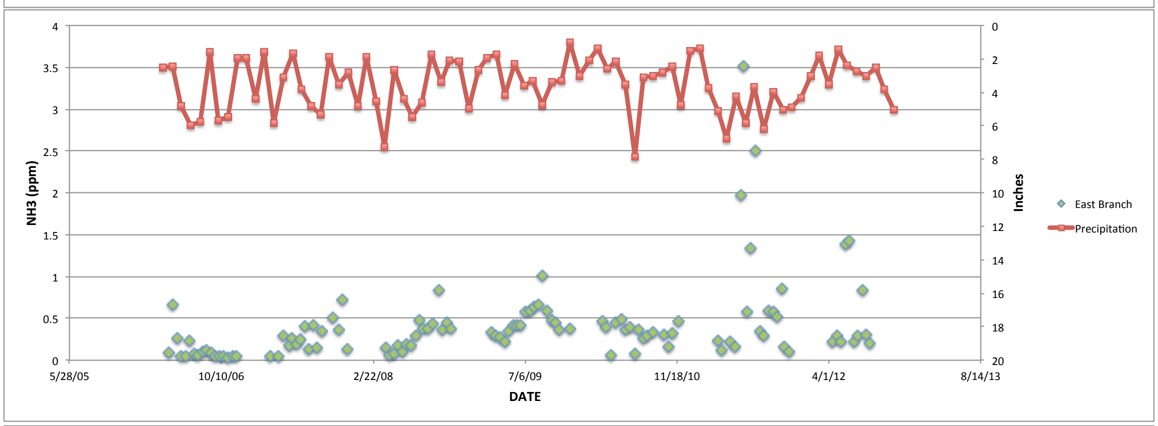


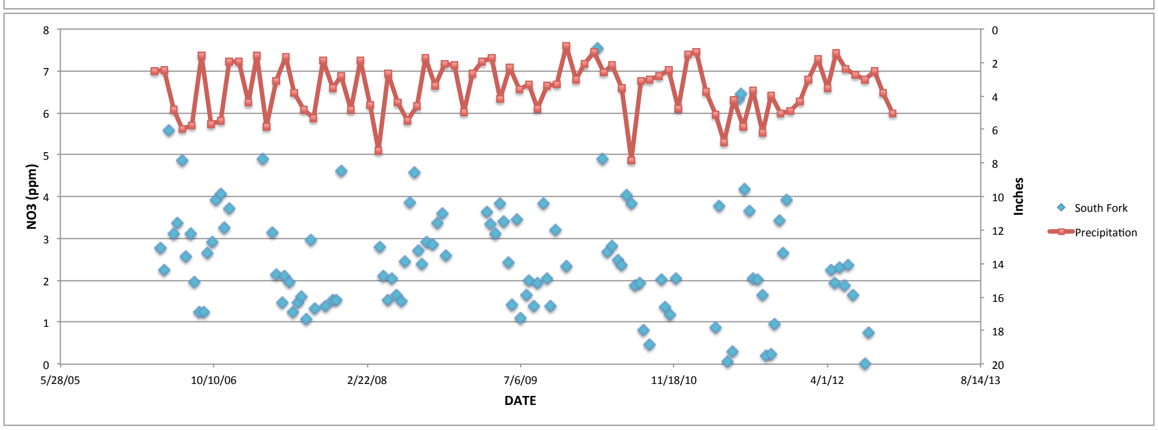

Annual
Spring
Summer
Autumn
Totat Nitrogen, ppm
PO4, ppm
Totat Phosphorus, ppm
SFork
EBranch

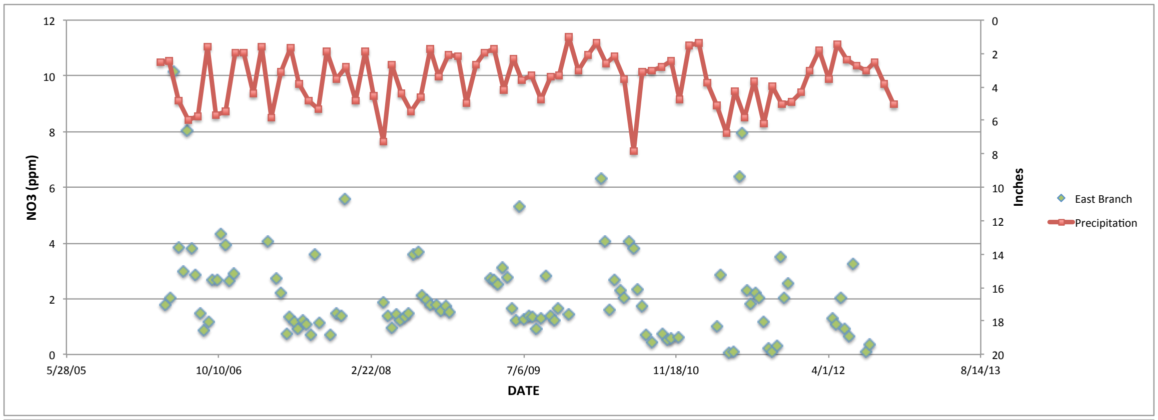
APPENDIX B

Monthly precipitation and nutrient concentration relationships

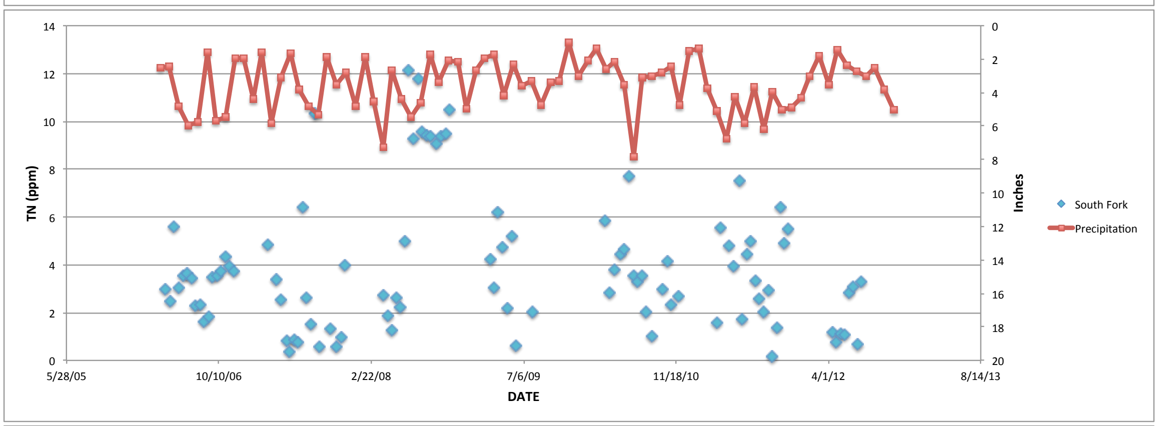




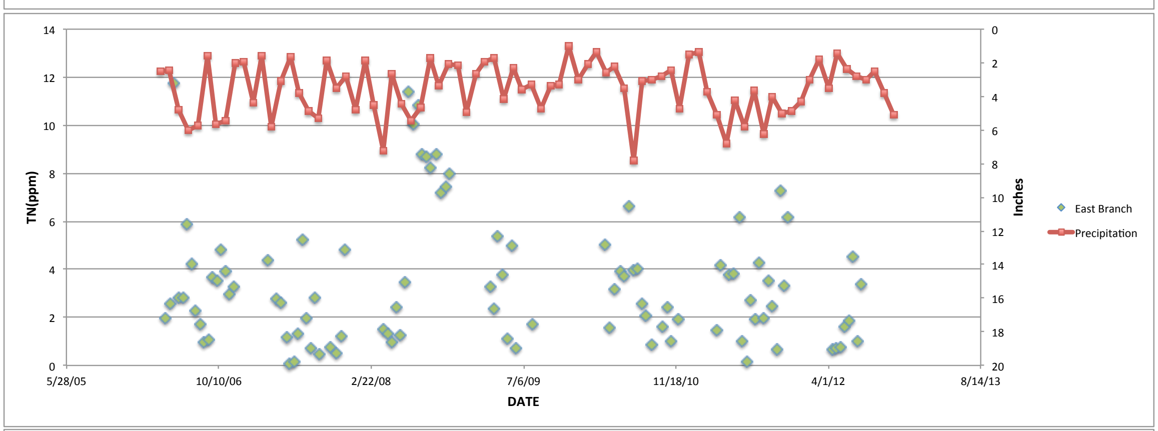




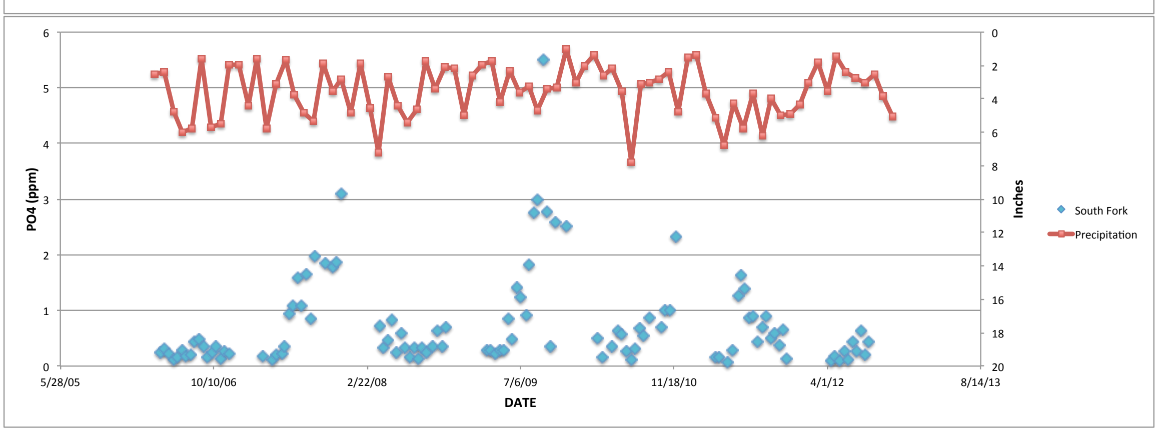
NO3 (ppm)
Inches
DATE
5/28/05
10/10/06
2/22/08
7/6/09
11/18/10
4/1/12
8/14/13
East Branch
Precipitation



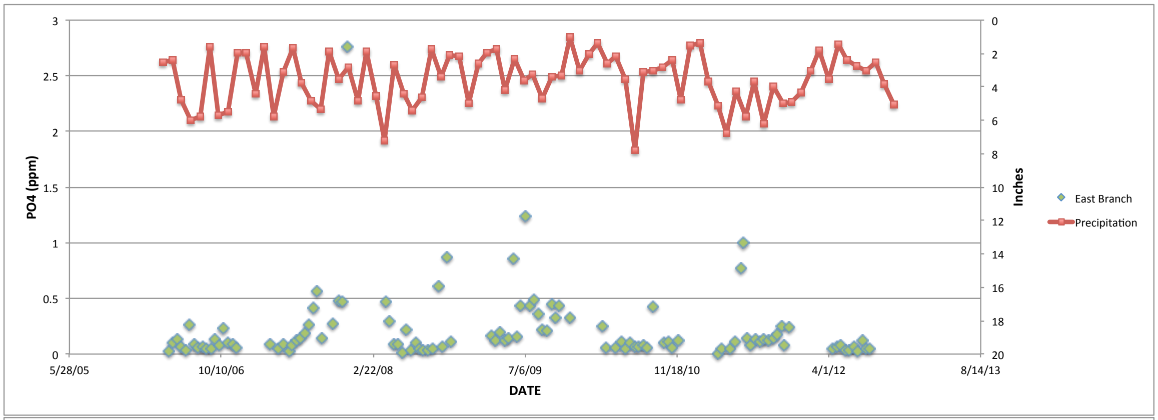
TN (ppm)
Inches
DATE
5/28/05
10/10/06
2/22/08
7/6/09
11/18/10
4/1/12
8/14/13
South Fork
Precipitation

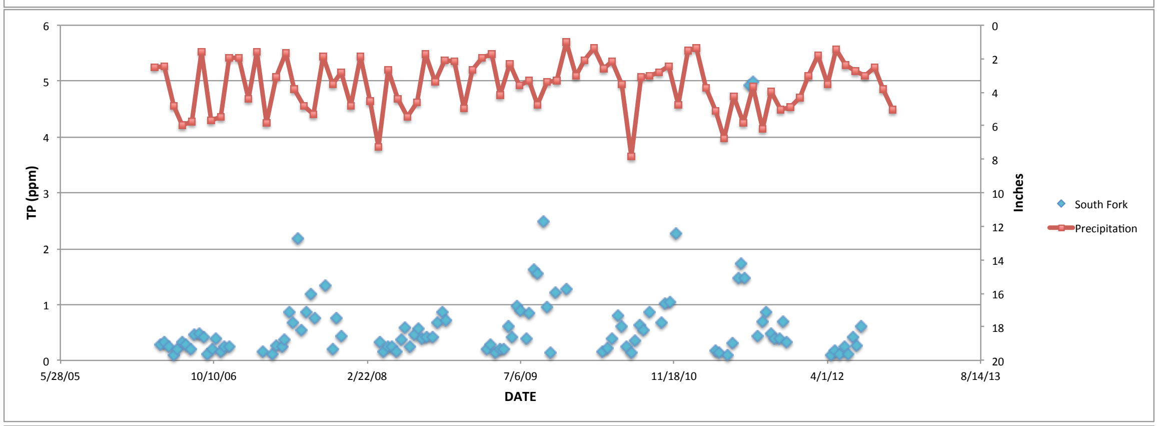


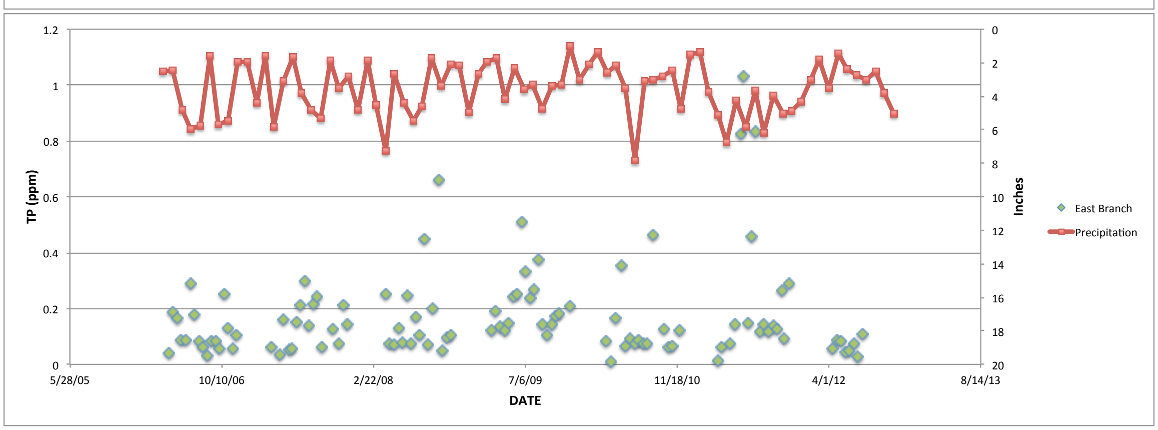
TN(ppm)
Inches
DATE
5/28/05
10/10/06
2/22/08
7/6/09
11/18/10
4/1/12
8/14/13
East Branch
Precipitation

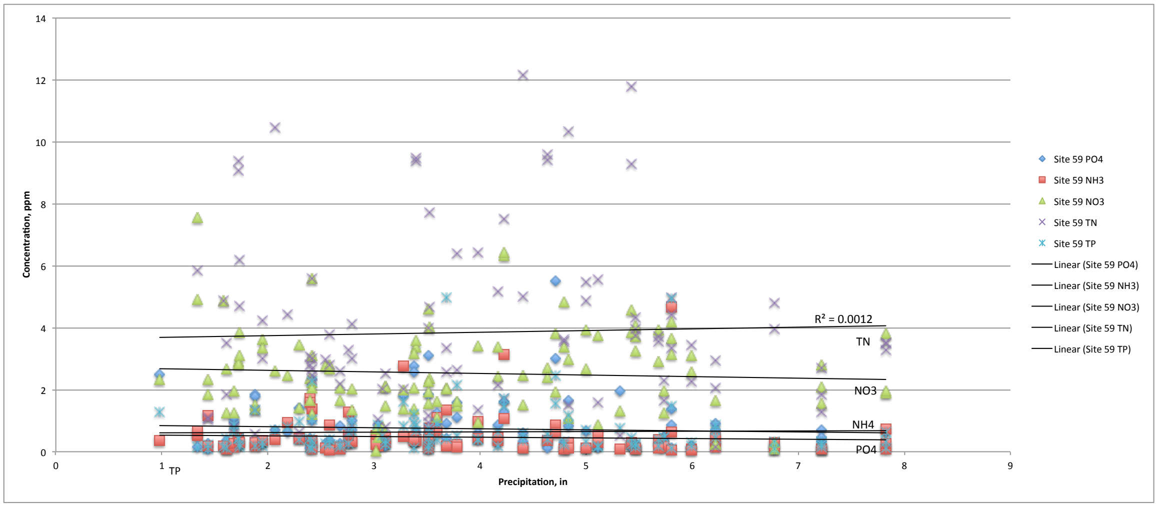


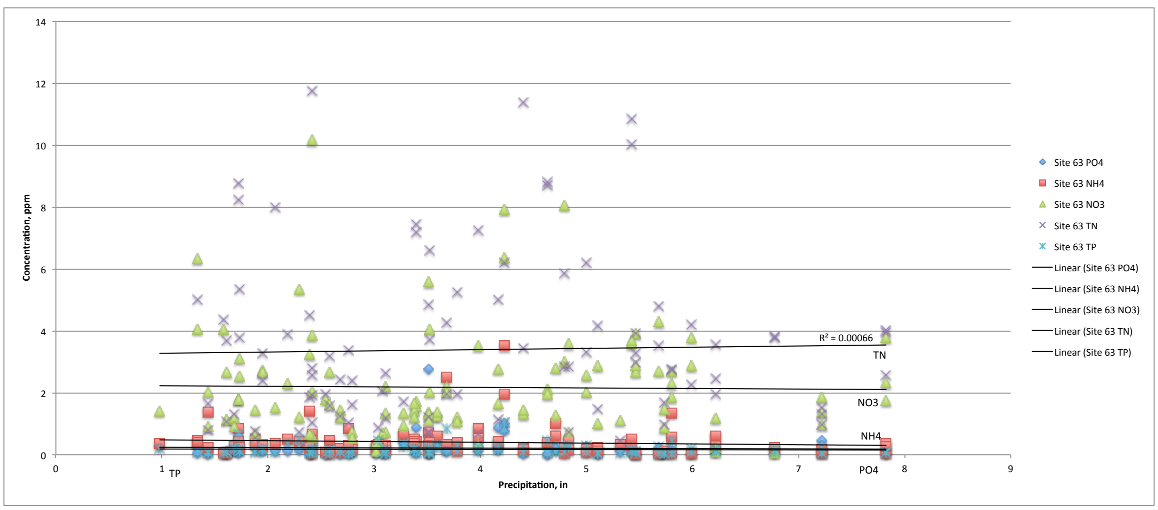
PO4 (ppm)
Inches
DATE
5/28/05
10/10/06
2/22/08
7/6/09
11/18/10
4/1/12
8/14/13
South Fork
Precipitation


PO4 (ppm)
DATE
Inches
East Branch
Precipitation


TP (ppm)
DATE
Inches
South Fork
Precipitation

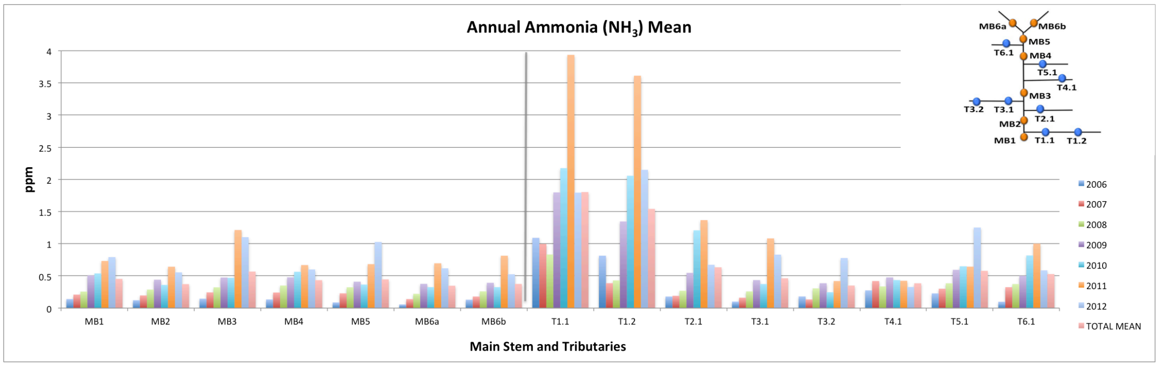

TP (ppm)
DATE
Inches
East Branch
Precipitation

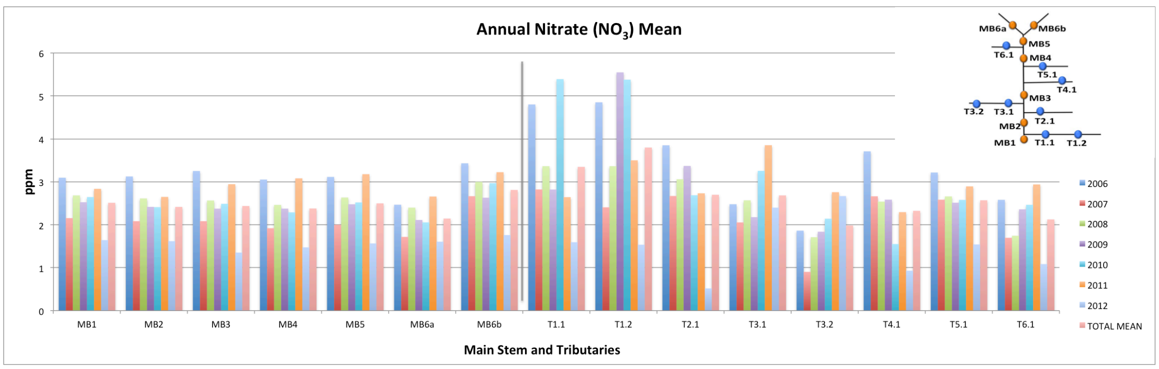

Concentration, ppm
Precipitation, in
R² = 0.0012
TN
NO3
NH4
PO4
TP
Site 59 PO4
Site 59 NH3
Site 59 NO3
Site 59 TN
Site 59 TP
Linear (Site 59 PO4)
Linear (Site 59 NH3)
Linear (Site 59 NO3)
Linear (Site 59 TN)
Linear (Site 59 TP)

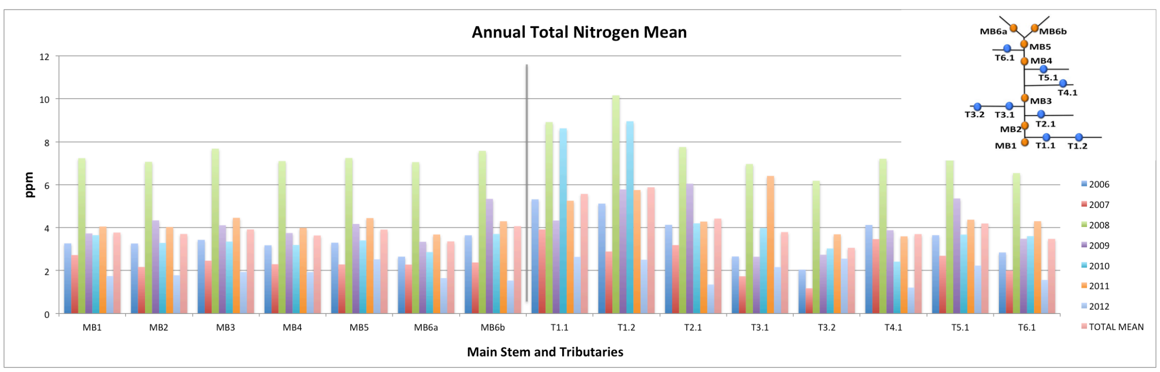

Concentration, ppm
Precipitation, in
R² = 0.00066
TN
NO3
NH4
PO4
TP
Site 63 PO4
Site 63 NH4
Site 63 NO3
Site 63 TN
Site 63 TP
Linear (Site 63 PO4)
Linear (Site 63 NH4)
Linear (Site 63 NO3)
Linear (Site 63 TN)
Linear (Site 63 TP)

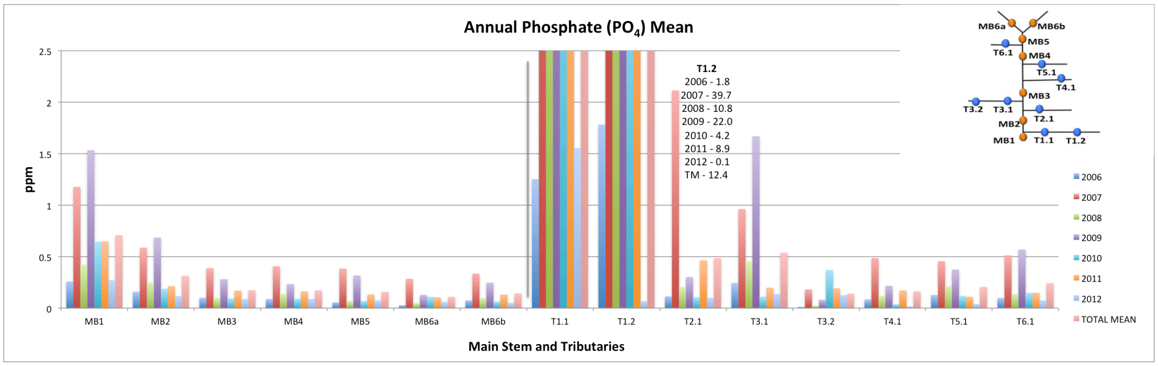
APPENDIX C

Annual concentrations at main branch (MB) left of the vertical line, and tributary (T) sample sites right of the vertical line from 2006-2012. Schematic in upper right corner provides channel network configuration of the tributary and mainstem sample locations.

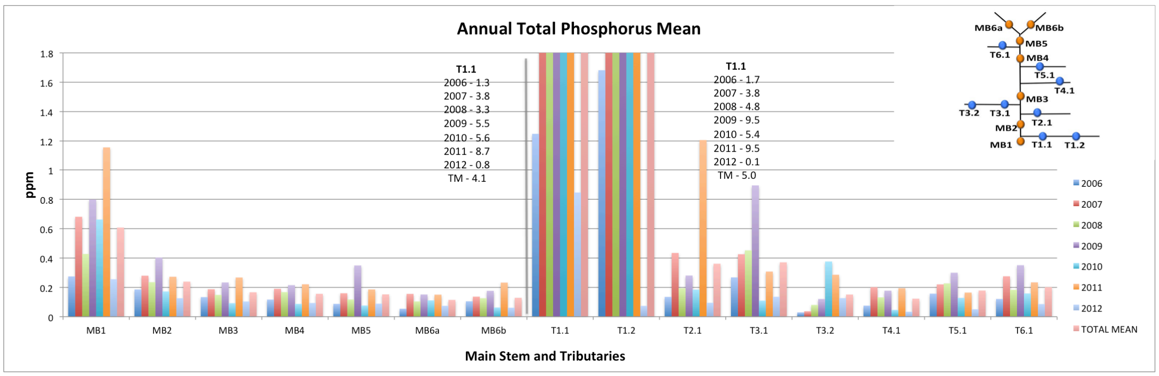








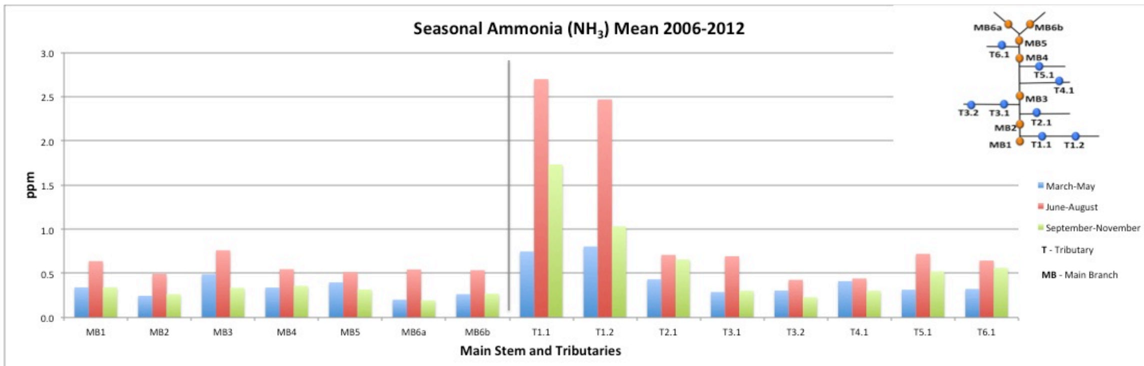
Annual Phosphate (PO_4) Mean
T1.2
2006 - 1.8
2007 - 39.7
2008 - 10.8
2009 - 22.0
2010 - 4.2
2011 - 8.9
2012 - 0.1
TM - 12.4
ppm
Main Stem and Tributaries
MB1
MB2
MB3
MB4
MB5
MB6a
MB6b
T1.1
T1.2
T2.1
T3.1
T3.2
T4.1
T5.1
T6.1
2006
2007
2008
2009
2010
2011
2012
TOTAL MEAN

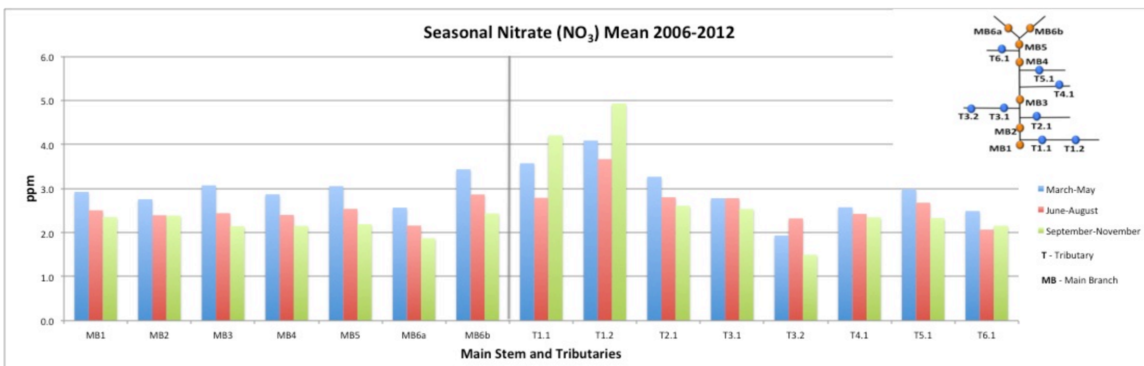


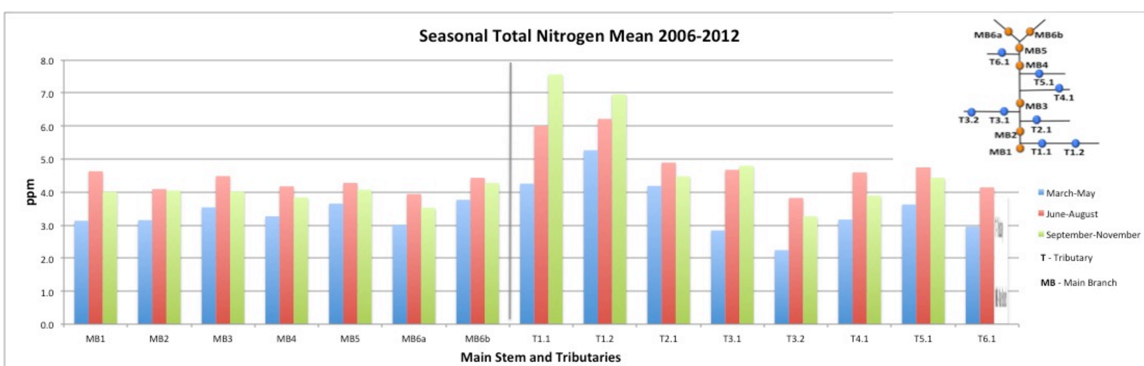
Annual Total Phosphorus Mean
T1.1
2006 - 1.3
2007 - 3.8
2008 - 3.3
2009 - 5.5
2010 - 5.6
2011 - 8.7
2012 - 0.8
TM - 4.1
T1.1
2006 - 1.7
2007 - 3.8
2008 - 4.8
2009 - 9.5
2010 - 5.4
2011 - 9.5
2012 - 0.1
TM - 5.0
ppm
Main Stem and Tributaries
MB1
MB2
MB3
MB4
MB5
MB6a
MB6b
T1.1
T1.2
T2.1
T3.1
T3.2
T4.1
T5.1
T6.1
2006
2007
2008
2009
2010
2011
2012
TOTAL MEAN

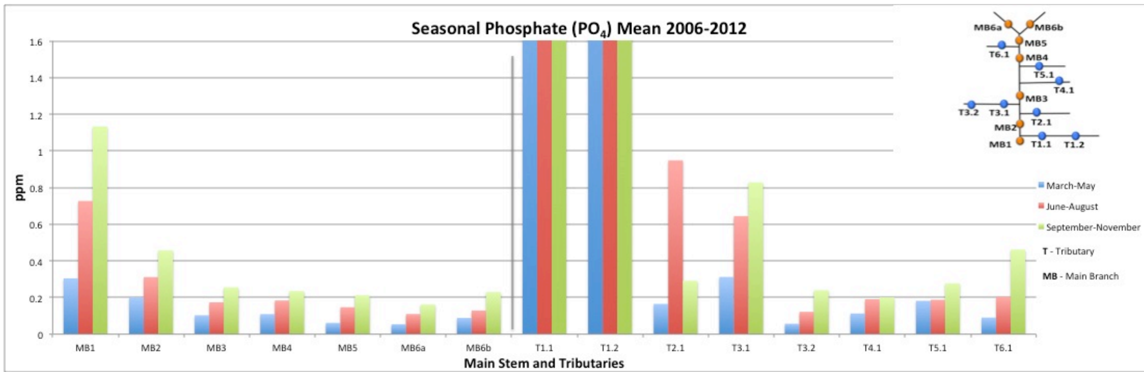
APPENDIX D

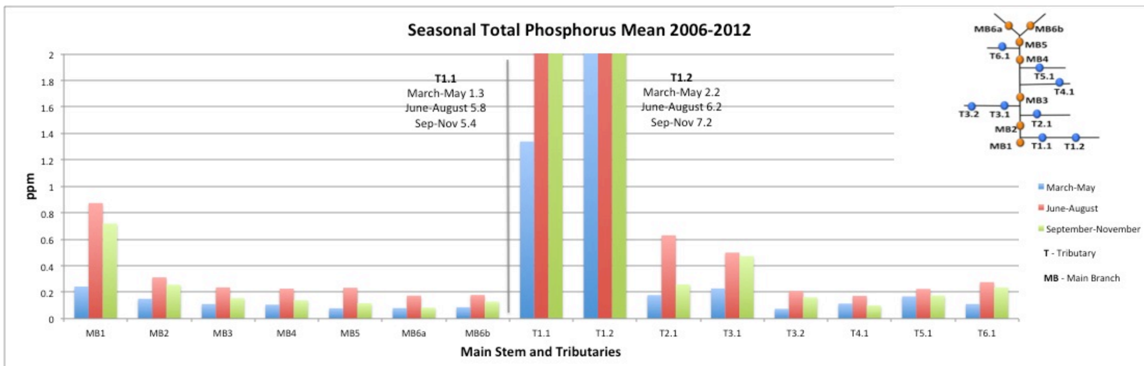
Seasonal concentrations at main branch (MB) left of the vertical line, and tributary (T) sample sites right of the vertical line from 2006-2012. Schematic in upper right corner provides channel network configuration of the tributary and mainstem sample locations.








Seasonal Phosphate (PO_4) Mean 2006-2012
ppm
Main Stem and Tributaries
MB1
MB2
MB3
MB4
MB5
MB6a
MB6b
T1.1
T1.2
T2.1
T3.1
T3.2
T4.1
T5.1
T6.1
March-May
June-August
September-November
T - Tributary
MB - Main Branch


Seasonal Total Phosphorus Mean 2006-2012
T1.1
March-May 1.3
June-August 5.8
Sep-Nov 5.4
T1.2
March-May 2.2
June-August 6.2
Sep-Nov 7.2
ppm
Main Stem and Tributaries
March-May
June-August
September-November
T - Tributary
MB - Main Branch